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Clear and Cloud-Free Lines-of-Sight From Aircraft

EUGENE A. BERTONI

21 June 1977

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METEOROLOGY DIVISION PROJECT 8624
AIR FORCE GEOPHYSICS LABORATORY
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The AFGL in-flight line-of-sight program that was initiated to collect observations of the presence, or absence, of clouds and haze on lines-of-sight at various elevation angles from aircraft has been completed. Approximately 270,000 unique observations were collected. Observations were taken by flight crews of the U.S. Air Force, U.S. Navy, American Airlines, several other U.S. commercial carriers, and NATO countries. Data were obtained over most of the Northern Hemisphere. → (over p 1473B)

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Observations taken within a 10° latitude-longitude sector were grouped together by altitude and season. The relative frequency of clear and cloud-free lines-of-sight are plotted in appropriate areas on Northern Hemisphere maps for various angular lines-of-sight. This paper describes the in-flight line-of-sight program, illustrates the presentation of data gathered, and gives a few examples of the utilization of this information.

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Foreword

The AFGL in-flight line-of-sight program collected observations of the presence or absence of clouds and haze at various elevation angles and at different altitudes during each of the four seasons of the year.

This report presents a description of the program, illustrates the presentation of the data gathered, and gives examples of the utilization of the data.

An Addendum to this report, classified Confidential, presents probabilities and analyses of clear and cloud-free lines-of-sight over much of the Northern Hemisphere. It is available from the Defense Documentation Center (DDC) to qualified individuals on request.

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Preface

The author is grateful to Mr. Iver A. Lund, Air Force Geophysics Laboratory, for his direction, guidance, and assistance throughout this entire program and to Mr. Norman Sissenwine who conceived and encouraged this effort and contributed many ideas and methods for presenting the data. Acknowledgment and appreciation is given to the following personnel who were liaison between AFGL and their organization: Col Ronald Bena, HQ USAF; Maj Glenn Michaels, and Mr. Walt Gallie, HQ AFSC; LtCol Robert Donohue and LtCol Harold Selfridge, HQ MAC; Maj Hugh Hanna, Maj John Benedict, Capt John Louer, and Capt T.K. Klein, HQ SAC; Maj Myles Rohrlick, HQ TAC; LtCol George Trusty, HQ PACAF; Maj Wendall Anderson, HQ USAFE; and Col W.H. Fairbrother, HQ AFLC, who arranged the participation of the three LOGAIR carriers: Overseas National, Universal, and Saturn Airways. The author is also grateful to Mr. Max Edelstein, LtCdr William S. Dehn and LtCdr Robert Riordon, U.S. Navy; Mr. Roger Flynn, Air Transport Association, who arranged for the participation of the following U.S. commercial air carriers on a voluntary, non-interference, no-cost-to-the-government basis: Trans World Airlines, National Airlines, Eastern Airlines, Ozark Airlines, and American Airlines.

Special recognition is given to American Airlines for its substantial contribution to this program from the beginning to end. This was made possible by the time and efforts of Mr. Paul M. Bishop, Manager—Flying Administration, who fully supported the endeavor and encouraged participation by American's pilots.

The United Kingdom and the Federal Republic of Germany contributed generously to this program. Other participating NATO countries were Canada, The Netherlands, Belgium, and Greece.

Regis College, under the direction of Sister Leonarda Burke (PhD), processed the thousands of observation forms into a format acceptable to the AFGL computer.

The support provided by the USAF Air Weather Service and their Detachments was invaluable. They provided aircrews with the necessary supplies to gather the LOS observations, answered questions about the program, encouraged active participation, checked observation forms for completeness, and mailed the forms back to AFGL. The cooperation and conscientious support of every aircrewman who participated in this program is especially appreciated.

Finally, I would like to extend appreciation to my colleagues in the Climatology and Dynamics Branch for their many suggestions and ideas for the formulation of this report, particularly Arthur J. Kantor and Donald D. Grantham; to Miss Melinda A. Zouvelos, Scientific Aid, who did an excellent job of plotting the enormous amounts of data onto Northern Hemisphere maps; and to Mrs. Helen M. Connell who was responsible for the typing of this report.

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Clear and Cloud-Free Lines-of-Sight From Aircraft

1. INTRODUCTION

Although many cloud cover and visibility statistics are available, numerous basic questions relating to actual seeing conditions to and from aircraft at altitude cannot be answered. What is the probability of seeing an object on the ground from various altitudes, in specified geographical areas, and at different seasons? How high must one fly to be 98 percent confident of being above all clouds? What is the probability of successful IR or optical detection of an aircraft or surface target from an aircraft flying above all clouds? These are three examples of questions that cannot be answered because suitable cloud and haze observations are not available. This conclusion was reached after trying to evaluate the effectiveness of some of the highly sophisticated systems that were used during the Southeast Asian conflict. The Climatology and Dynamics Branch (LYD) of the Air Force Geophysics Laboratory (AFGL) has been attempting to remedy this situation with an intensive research program to provide estimates of the probability of clear lines-of-sight (CLOS), that is, both haze-free and cloud-free, and cloud-free lines-of-sight (CFLOS) through the atmosphere. Related research projects consist of estimating the probability of CLOS through the entire atmosphere from

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routine sky cover and sunshine observations;[1] estimating the probability of CFLOS from whole-sky photographs;[2] and developing models that can be used to obtain CFLOS probabilities for locations where only climatological records of routine cloud cover observations are available.[3]

From April 1965 to October 1966 a test program to collect actual in-flight line-of-sight (LOS) observations was conducted. Approximately 72,000 observations were gathered and described by Bertoni.[4] Results of this program provided genuine insight into problems related to Air Force reconnaissance, search and track, and, for the first time, a good "feeling" for the "seeing" environment in which some military electro-optical systems would have to function.

It was determined, from the pilot program, that realistic estimates of the probability of clear, cloud-free and haze-free lines-of-sight could be derived from a large sampling of actual in-flight observations. Such estimates are required in systems design for determining the utility of optical and infrared weapon, search, track, communication, and target-detection systems. These estimates are also required for operational planning. Consequently, a major effort, to be carried out over a 5-year period, was initiated. In this paper the data gathered from this program are presented, described, and analyzed.

2. THE LOS PROGRAM

Again, as with the pilot program, it was deemed that the most economical and practical method of obtaining LOS data was to employ USAF aircraft and crews on routinely flown missions over frequently flown routes in the Northern Hemisphere. The USAF Military Airlift Command, Strategic Air Command, Tactical Air Command, Pacific AF, USAF in Europe, USN patrol aircraft, contract air carriers of the USAF, commercial U.S. air carriers, and NATO countries participated in the data collection program, on a mission non-interference basis.

This follow-on in-flight LOS data gathering program started in April 1968. Observations were collected during the mid-season months of January, April,

1. Lund, I.A. (1965) Estimating the probability of clear lines-of-sight from sunshine and cloud-cover observations. J. Appl. Meteor, 4:714-722.
2. Shanklin, M.D., and Landwehr, J.B. (1971) Photogrammetrically Determined Cloud-Free Lines-of-Sight at Columbia, Missouri. Final report under contract F19628-68-C-0140, AFCRL 185 pp.
3. Lund, I.A., Grantham, D.D., and Elam, C.B. (1975) Atlas of Cloud-Free Line-of-Sight Probabilities Part 1: Germany. AFSG 309 (AFCRL-TR-75-0261) 77 pp.
4. Bertoni, E.A. (1967) Clear Lines-of-Sight from Aircraft. AFSG 196, AFCRL-67-0435, 186 pp.

July, and October. Since weather information for any one year is not sufficiently representative of the climate of any geographic area, at least several years of observations were required to assure that probabilities estimated from the observations would be adequately representative of the true climatology for each area. As a result, the program was intended to last for a period of 3 to 5 years, with the actual duration dependent upon findings, and on problems of maintaining the program. Since the earlier effort of continuous data collection tended to wither after a little more than 1 year, it was decided to obtain observations every third month, rather than every month, to keep the program viable and make it more palatable to flight crews collecting meaningful data. The program actually continued for more than 6 years, terminating in January 1975.

For the preliminary effort, lines-of-sight were observed along elevation angles of 0° (horizon), ±30°, and ±90° relative to the horizon. We had concluded that some inconsistencies in the early findings were due to poor estimates of these elevation angles. Therefore, AFGL developed a clinometer for better estimation of these angles. Figure 1 is an illustration of an airman using the clinometer.

Figure 1. Illustrating the Use of the Clinometer Especially Designed for Taking Line-of-Sight Observations

It consists of a 4-in. plastic tube, approximately 2 in. diam, containing a gravity-actuated disc that indicates the five required "look angles" of 0° (horizon), ±30°, and ±60° relative to the horizon. (Since it was impracticable to observe at ±90° from most positions in an aircraft, the follow-on program requested observations of LOS be taken at ±60° instead of ±90°.) The observer looks through the clinometer at a point on the horizon (0°), to the sky at +30° and +60° above the horizon, and to the earth's surface at -30° and -60° below the horizon, a total of five "look angles."

The observation recording form devised for military aircrews, Figure 2, required an aircrew member to check whether each of the five lines-of-sight were

INSTRUCTIONS: Take cruise observations one each hour or at regular observing/reporting time. Use Clinometer to determine sighting angles. Observations should be taken from position in aircraft that given optimum up and down visibility. Check appropriate column on form after logging time, position and altitude (see reverse side).

CHECK APPROPRIATE COLUMN(S) IN RECORD BELOW

CLEAR (CLR) - SKY, GROUND OR HORIZON DISCERNIBLE

CLOUDS (CLDS) - SKY, GROUND OR HORIZON OBSTRUCTED BY CLOUDS

HAZE - SKY, GROUND OR HORIZON OBSTRUCTED BY HAZE

MAIL COMPLETED FORM TO:

AFCRL (CREW)
L. G. HANSCOM FIELD
BEDFORD, MASSACHUSETTS 01730

LINE OF SIGHT OBSERVATIONS

DEPART (*City, State, Country*)	CIG	VIS	TYPE AIRCRAFT
ARRIVE (*City, State, Country*)	CIG	VIS	FLT NO/TRACK

OBSERVER	DATE (GMT)	ORGANIZATION

HOUR (GMT)	LAT	LONG		ALTITUDE (29.92)	0° (Horizon)			+ 30°			+ 60°			− 30°			− 60°		
					CLR	CLDS	HAZE	CLR	CLDS	HAZE	CLR	CLDS	HAZE	CLR	CLDS	HAZE	CLR	CLDS	HAZE
			CLIMB	5000															
				10000															
				20000															
				30000															
			CRUISE																
			DESCENT	30000															
				20000															
				10000															
				5000															

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Figure 2. Line-of-Sight Observation Form

clear, cloudy, hazy, or both cloudy and hazy. Observations were obtained on climb and descent at altitudes of 5,000, 10,000, 20,000, and 30,000 ft, and once

each hour during cruise. Time and aircraft position of each observation were also recorded along with altitude at cruise. Observations were generally taken in the direction the aircraft was heading, but any convenient azimuth that allowed optimum up-and-down visibility was permitted. For positive elevation angles (+30° and +60°), clear (CLR) was checked on the form when blue sky was clearly visible; if the sky was grey and dull, HAZE was checked; and if there was evidence of cloud structure, CLDS (clouds) was checked. The horizon (0°) was defined as the distant line along which earth and sky appear to meet. If the point on the LOS was distinct, CLR was checked; otherwise, either CLDS or HAZE was checked. For negative elevation angles (-30° and -60°), CLR was checked if large features (rivers, roads, sea swells, etc) were distinctly visible; if they were very diffuse, HAZE was checked; if cloud structure obstructed the LOS, CLDS was checked. If both clouds and haze obstructed the line-of-sight, CLDS and HAZE were both checked.

Figure 3 is a copy of the observation recording form used by the U.S. commercial carriers. The carriers made LOS observations on a voluntary, non-interference basis, at no cost to the government. Crew duties and FAA regulations restricted LOS observations to altitudes generally above 20,000 ft and over the CONUS.

Observations were taken only during daylight hours, since we had noticed that nighttime lines-of-sight were too often reported clear and were undoubtedly biased.

Roughly 270,000 observations were obtained over the Northern Hemisphere from the equator to 80°N latitude, except between longitudes 40°E and 100°E. Approximately 56,000 of these observations were obtained during winter (December, January, February); 82,000 during spring (March, April, May); 60,000 during summer (June, July, August); and 72,000 during autumn (September, October, November). For analysis purposes, the hemisphere was divided into 10° latitude-longitude sectors. Probabilities of clear and cloud-free lines-of-sight were calculated from the observations in each sector. Values are given for five angles of vision (0°, ±30°, ±60°), the four seasons, and the following divisions of altitude: below 2500 ft, 2500 to 4999 ft, 5000 to 9999 ft, 10,000 to 14,999 ft, 15,000 to 24,999 ft, 25,000 to 34,999 ft, 35,000 to 44,999 ft, and 45,000 ft and above. Sectors with fewer than 10 observations were disregarded. Aircraft heading and position within each 10° latitude-longitude sector were not considered. These probabilities are presented by season in the Addendum of this report in Appendices A, B, C, and D as a function of altitude and "look-angle."

DEPART (City, State)	CIG	VSBY	AIRLINE/FLIGHT #
ARRIVE (City, State)	CIG	VSBY	DATE (GMT)
DEPART (City, State)	CIG	VSBY	AIRLINE/FLIGHT #
ARRIVE (City, State)	CIG	VSBY	DATE (GMT)
DEPART (City, State)	CIG	VSBY	AIRLINE/FLIGHT #
ARRIVE (City, State)	CIG	VSBY	DATE (GMT)

HOUR GMT	U. S. LOCATION * CHECK POINT	FLIGHT LEVEL	0° (Horizon)			+30°			60°			−30°			−60°		
			CLR	CLDS	HAZE	CLR	CLDS	HAZE	CLR	CLDS	HAZE	CLR	CLDS	HAZE	CLR	CLDS	HAZE

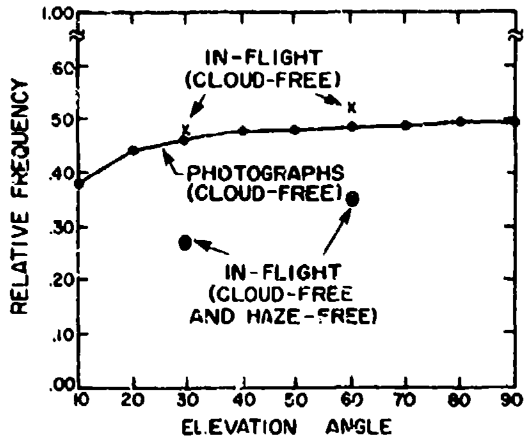
* USE ATC Checkpoint Designator (MFR for Medford)

Figure 3. Line-of-Sight Observation Form Used by Commercial Air Carriers

3. COMPARISON

Figure 4 provides a comparison between actual frequencies of clear and cloud-free lines-of-sight to the ground in the 5° latitude-longitude sector around Columbia, Missouri, and an analysis of hourly whole-sky photographs taken over a 3-year period from the National Weather Service station at Columbia.

Figure 4. Relative Frequencies of CLOS and CFLOS Obtained From Whole-Sky Photographs and In-Flight Observations



The X's shown in Figure 4 represent the percent of time airborne observers at altitudes above 35,000 ft reported cloud-free lines-of-sight to the ground. Cloud-free conditions were reported 48 percent of the time at a depression angle of 30°, and 52 percent of the time at a depression angle of 60°.

The curve labeled "photographs" represents probabilities of CFLOS from the ground through the entire atmosphere at Columbia, Missouri, during daytime. CFLOS probabilities estimated from the in-flight observations (X's) are in excellent agreement with estimates based on the photographs. Since there are times when clouds were reported above the aircraft but not on the line-of-sight below the aircraft, probabilities estimated from the in-flight observations should be and are higher than those estimated from photographs. Cloud and haze-free LOS probabilities are shown by the two points labeled (X). At a 30° depression angle the probability of a CLOS is 27 percent, at -60° the CLOS probability is 35 percent. These CLOS ((X)) and CFLOS (X) probabilities are based on 918 in-flight observations taken at altitudes above 35,000 ft within approximately 150 nautical miles of Columbia, Missouri.

4. ANALYSIS

The altitudes for which most in-flight line-of-sight observations were taken are between 15,000 and 35,000 ft. These are the altitudes where most jet flights are made. Analysis of the probabilities of clear and cloud-free LOS for these altitudes are shown in the Addendum of this paper. The solid red isopleths are drawn over the data and indicate a higher degree of confidence in the analysis

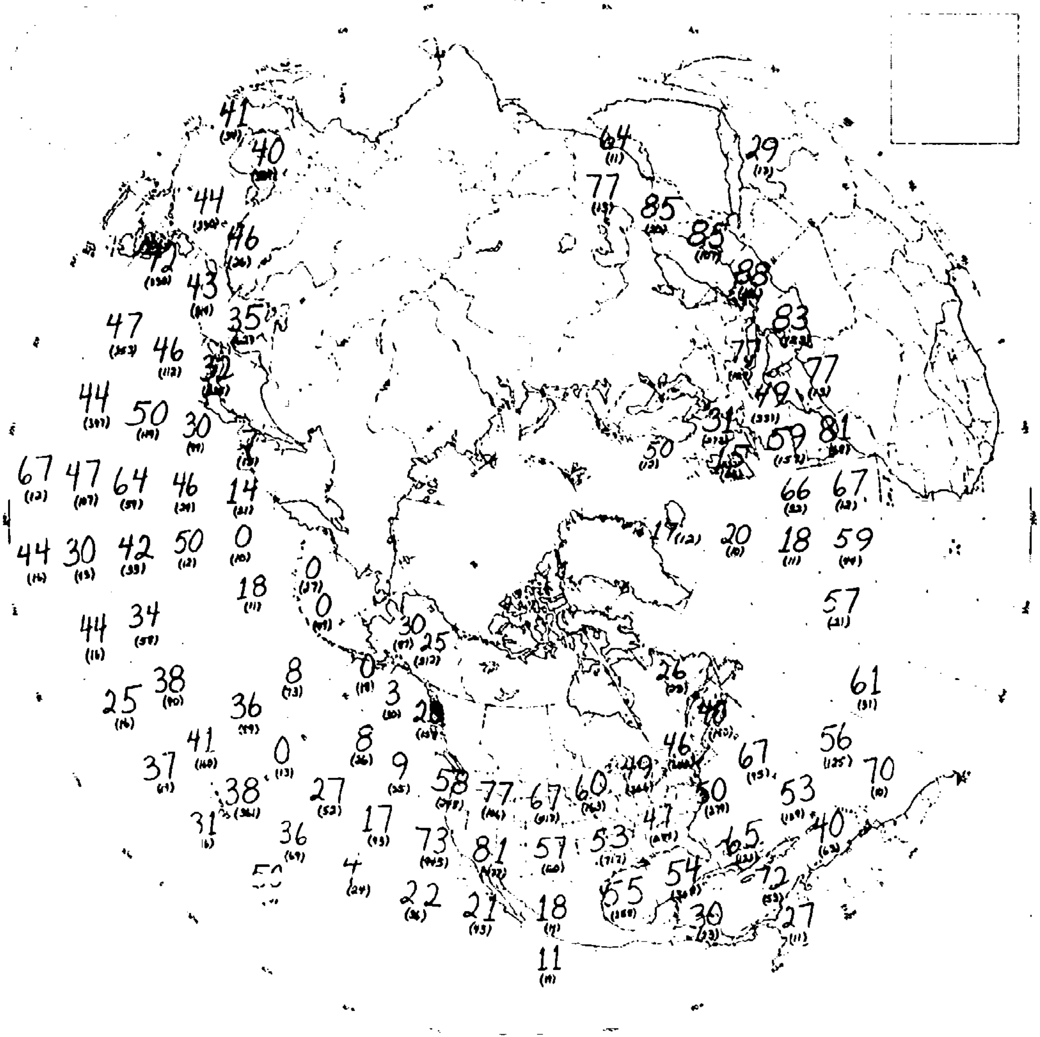


Figure 5. Estimates of the Frequency of a CFLOS (Number of observations are shown in parentheses)

than do the dashed lines that are drawn over regions of limited observations. A conscientious effort was made to insure consistency in the analysis.

Figure 5 illustrates how the probabilities of clear and cloud-free LOS are presented. The large numbers are the percent probabilities. The smaller numbers, in parentheses, indicate the total number of observations taken within each of the 10° latitude-longitude sectors. (No values were plotted in sectors that had

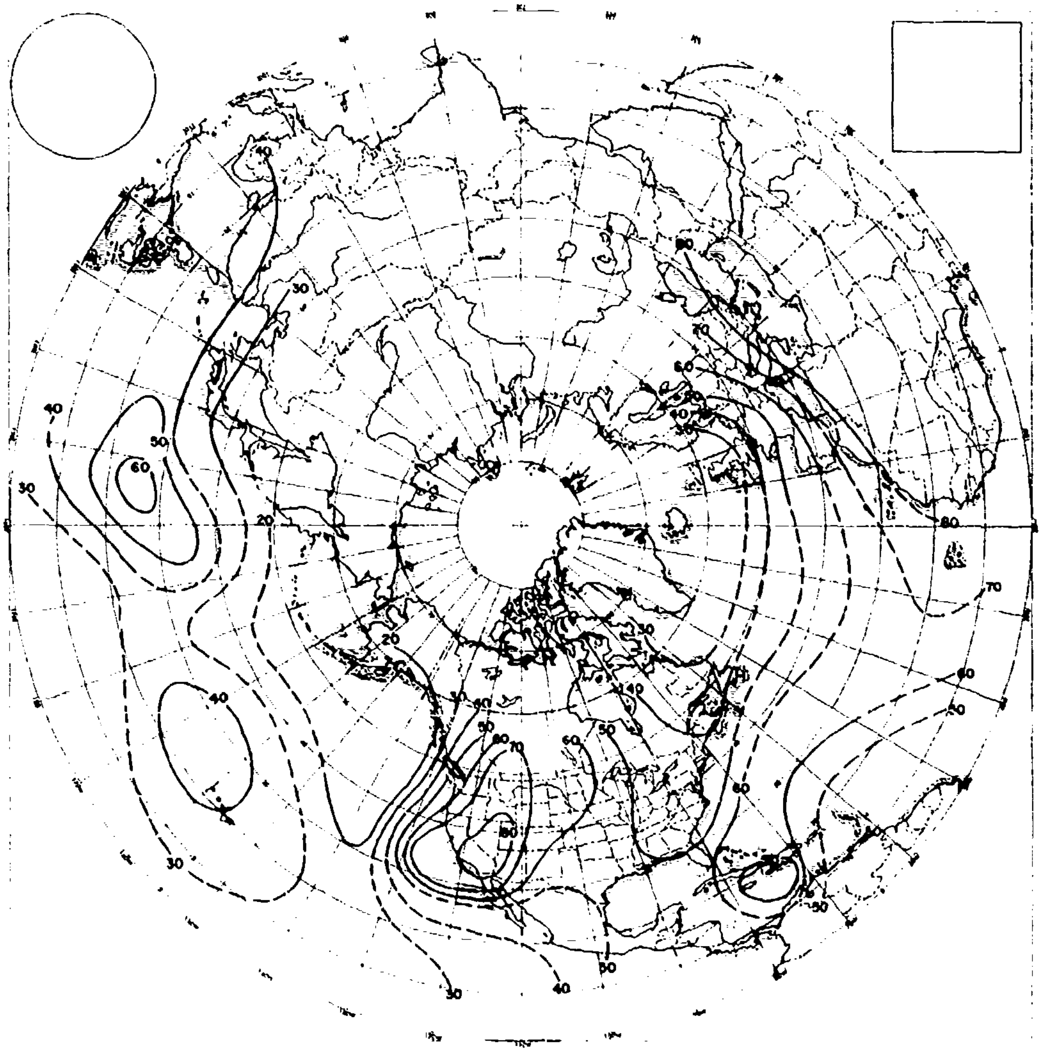


Figure 6. An Analysis of Figure 5

fewer than 10 observations.) For example, in the sector 30° to 40° N latitude and 80° to 90° W longitude, the probability of a CFLOS is 47 percent based on 288 in-flight observations.

Figure 6 is the author's analysis of Figure 5. In the Appendix of the Addendum of this paper, analyses have been done for the altitude layers 15,000 to 24,999 ft (20,000 ft) and 25,000 to 34,999 ft (30,000 ft). Data (that is, Figure 5) and analysis (that is, Figure 6) have been incorporated to form one illustration.

5. UTILITY

During the data-collection period, 3L received many specific requests for information needed for the design and evaluation of systems using optical and infrared sensors with surface and airborne search, track, communication, and weapon systems. We have provided probabilities for use in many of these problems, some of which were not anticipated when the program was initiated. A few examples of the application of these data follow:

a. Of particular concern for the conceptual design of reentry vehicles (RV) is the probability of erosion due to ice crystal clouds because of higher reentry speeds at high altitudes where such clouds are present. The occurrence of clouds on a LOS elevation angle of 30° above the horizon is closely related, since typical reentry trajectories are between 20° and 30° to the horizontal at these altitudes. Figure 7 depicts probabilities of a CFLOS along a 30° elevation angle. At 30,000 ft, the probability of a clear LOS (the solid line) at +30° is 75 percent. Therefore, reentry vehicles that have descended to 30,000 ft will have penetrated clouds and haze with a probability of 25 percent. The dashed line gives the probability of a cloud-free LOS of 84 percent at 30,000 ft; thus an RV penetrated clouds with a probability of 16 percent. Even at 40,000 ft the probability of an RV passing through clouds is 6 percent, still appreciable if considered against accepted calculated risk for design. The difference between these two curves is interpreted as haze.

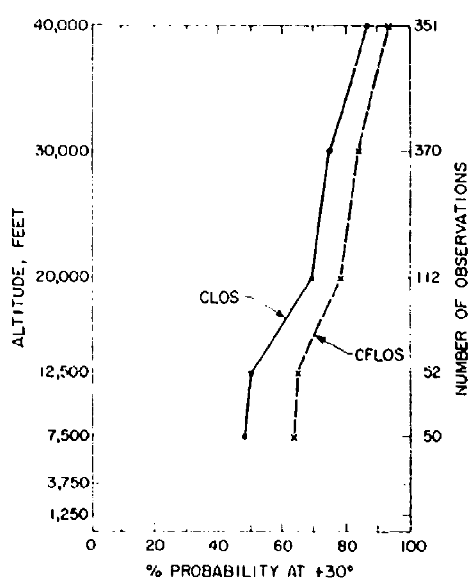


Figure 7. Probability of Clear (solid line) and Cloud-Free (dashed line) Lines-of-Sight

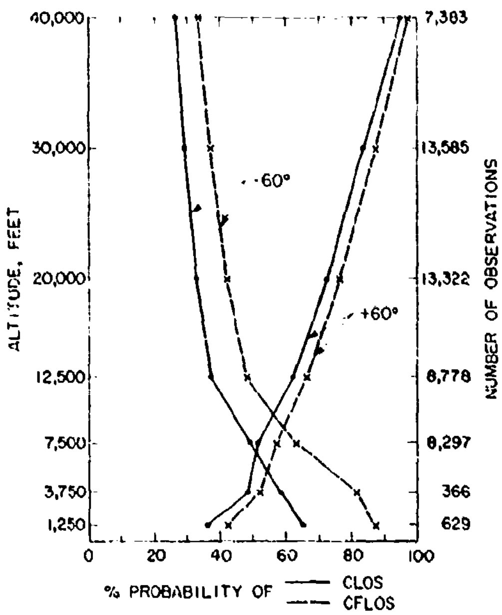


Figure 8a. Probability of Clear and Cloud-Free Lines-of-Sight Over the Northern Hemisphere in Winter (56,000 observations)

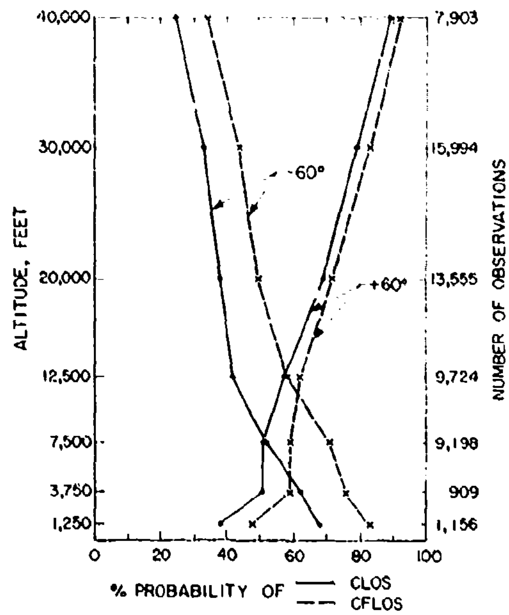


Figure 8b. Probability of Clear and Cloud-Free Lines-of-Sight Over the Northern Hemisphere in Summer (60,000 observations)

b. Communications between satellites, aircraft, and the earth's surface is another area of interest. Figure 8a shows profiles of CLOS and CFLOS as a function of altitude during winter for the 60° elevation and depression angles. At 30,000 ft the probability of a CLOS to the sky at +60° is 83 percent, based on about 13,585 observations. The probability of a CFLOS is 87 percent. Thus, if haze is unimportant to communication systems and only clouds will cause interference, the probability of unsuccessful communication from this altitude to a satellite is 13 percent. Looking to the earth's surface at -60° from 30,000 ft, the probability of CLOS or CFLOS is 29 and 37 percent, respectively. Therefore, the probability of unsuccessful communication at -60° from aircraft to the ground because of clouds is 63 percent. Figure 8b shows profiles of CLOS and CFLOS as a function of altitude for +60° during the summer. A comparison with Figure 8a shows differences of about 5 percent between probabilities of CLOS and CFLOS looking up from altitudes above 20,000 ft.

Figure 9 is an analysis of the more than 270,000 in-flight line-of-sight observations. Questions of whether or not a certain operation is feasible over a given season and location cannot be answered from this illustration, but much information can be obtained that is important in the general design and operation of an

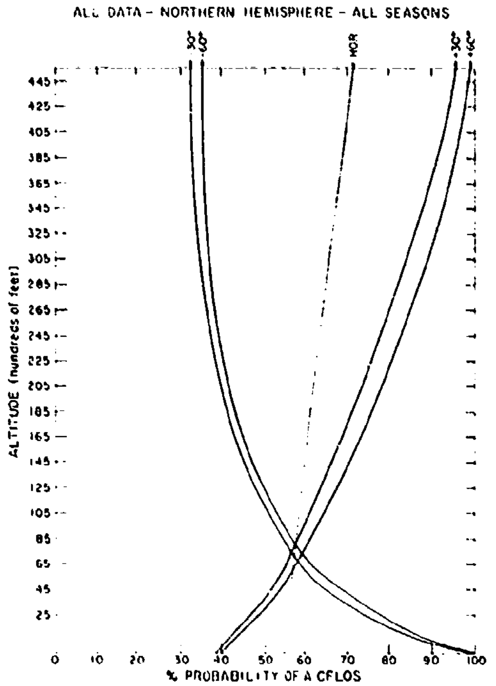


Figure 9. A Smoothed Analysis of the Probabilities of Cloud-Free Lines-of-Sight Over the Northern Hemisphere for All Seasons Combined (270,000 observations)

airborne system. All data points, plotted every 2000 ft (not shown) beginning at 2000 ft, were subjectively analyzed to give these curves. The curves are not intended to be representative of any given season or location, but are drawn to illustrate how the probability varies with altitude. Some interesting information obtained from this graph is: (a) from an altitude of 45,000 ft the sky above at +30° cannot be seen 5 percent of the time, (b) the ability to see the horizon from an aircraft varies from 55 percent at 2500 ft to nearly 62 percent at 45,000 ft, and (c) above 30,000 ft the probability of seeing the earth's surface at -30° and -60° is nearly constant at 33 and 36 percent, respectively.

6. SUMMARY

The relative frequencies of clear and cloud-free lines-of-sight plotted on the maps in appendices of this paper are based on the unique collection of more than 270,000 in-flight observations. This information is needed to properly design and

evaluate the usefulness of surface and airborne systems that employ visual and infrared sensors. They are also valuable for operational planning. The in-flight observations were taken by many different observers, from a wide variety of aircraft, during daylight hours only, at selected angles of vision, mostly during the midseason months, and over much of the Northern Hemisphere. The data were summarized by season, altitude, angle of vision, and 10° latitude-longitude sectors.

These observations are unique and the probability estimates determined from them provide a good approximation of actual seeing conditions from an aircraft in flight.